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Report No. 710/42
Watertown Arsenal

May 16, 1935

GROOVED ARMOR PLATE

References: 97th Partial Report of Test of Thin Armor Plate, Aberdeen Proving Ground, Md. April 15, 1935. Watertown Arsenal Report #710/32.

Abstract

This report is a comparison of grooved armor plate and flat armor plate of equal weight and the same composition and heat treatment. The results used for grooved plates are those taken from P.R. 97, APG. Those for flat plate were taken from a summary of all of this type tested at the Proving Ground and covered in P.R. 1 to 97, APG.

(a) The grooved plate is feasible and economical to roll and heat treat.

(b) It is from 9% to 50% better than an equivalent weight of the same plate without grooves.

(c) Grooved plate of the same weight as 1/2" armor plate successfully withstood the cal. .30 A.P. T1 (High Vel.) bullet at 100 yds. The T1 ammunition was developed to penetrate 1/2" plate at 300 yds., as reported in Minutes of the Ordnance Committee Meeting, held Thursday, May 10th, 1934.

Satisfactory homogeneous armor plate has been made for the last eight years of the following steel composition:

C	Mn	P	S	Si	Cr	Mo	V
.45/.55	.40/.70	∠.03	∠.03	.15/.25	1.10/1.30	.60/.80	.20/.30

Plates of this composition have been heat treated by quenching in oil from (870°C) 1600°F and drawing at about (618°C) 1150°F - to 418-444 Brinell hardness.

The possibilities of increasing ballistic efficiency by using a given weight of plate in such a manner as to deflect and break up bullet cores, has been investigated at this Arsenal during the last two years. The results obtained are set forth in W.A. 710/32. The use of a hard thin front plate of the same material was found to help resist penetration in the bottoms of the grooves, as shown in the above report.

Three plates of the composition shown above were machine-grooved in the annealed condition and then hardened in the same manner as flat plate of the same composition. The types and dimensions of the grooves are shown in Figures 1, 2, and 3. These plates, designated G10, G11, and G12, with and without thin cover plates, were tested at the Aberdeen Proving Ground, March 11 to 14, 1935. The 97th Partial Report of Test of Thin Armor Plate shows the results obtained. For convenience these results are summarized in Table 1.

TABLE I

Equivalent Weight and Ballistic Limits of Grooved Plates

Plate No.	Wt. per Sq. Ft.	Equivalent Thickness of Flat Plate	Ammunition	Ballistic Limit-f.s.	Spec. AXS54 Rev.2-Requirement for Equiv. Flat Plate
G10(with 1/8" cover plate)	21.5#	0.513"(nominal 1/2")	.30APM1922	>2701	2250
			.30APT1High Vel.	>2947	none
			.50 APM1	1596	none
G11(no cover plate)	18.9#	0.451"(nominal 7/16").	.30APM1922	2478	2090
			.50APM1	1537	none
G11(with 1/8" cover plate)	24.0#	0.576"(nominal 9/16").	.30APM1922	>2703	none
			.30APT1High Vel.	>2897	none
			.50APM1	>1769(a)	1930 (b)
G12(no cover plate)	14.0#	0.331"(.004" over limit for 5/16")	.30APM1922(h)	2460	1790(5/16")
			(same)(vh)	2421	1790(5/16")
G12(with 1/8" cover plate)	19.0#	0.453"(.001" over limit for 7/16").	.30APM1922	2590	2090(7/16")
			.50APM1	1450	none

Note: > - Highest Velocity used. B.L. not yet reached.

(a) - Lack of test space prevented further firings.
(b) - No specified B.L. Figure obtained by interpolation AXS54-Rev.2
(h) - Impact located on slope of groove.
(vh)- Complete penetration at bottom of groove-partial on slope.

It is evident that these plates displayed greater ballistic resistance than that required in present specifications for flat plates of the same weight. This excess ballistic resistance, expressed as percentage of the required ballistic limit was as follows:

Plate	Exceed Required Ballistic Limit by
G10	more than 20%
G11(w/o cover plate)	18 1/2%
G11(w/cover plate)	no result-lack of test area
G12(w/o cover plate)	36 1/2%(average)
G12(w/cover plate)	24%

However, it is well understood that all plates must exceed the ballistic requirement and that many of the plates tested do surpass the required limits by a considerable margin. Therefore, the efficiency of these grooved plates should be shown by comparison with actual results rather than with specified ballistic limits.

Reports of Test of Thin Armor Plate from 1932 to date are shown in Partial Reports 1 to 97, Aberdeen Proving Ground. The earlier results are not comparable with those now obtained due to differences in range, ammunition, etc. They will not be included in this study. The great mass of the available data was obtained under Tent. Spec. 31 which recognized a much different definition of "complete penetration" than that used at

present in Spec. AXS54. It seems desirable to include the data thus available but, for this purpose, it will be necessary to convert the ballistic limits of earlier firings to the substantial equivalent of those of Spec. AXS54. Lest such conversion may seem unfair the results obtained with the grooved plates will be compared:

(a) with results of all firings under Spec. AXS54,-Rev 1., and -Rev. 2.

(b) with results of all firings under like conditions of range and ammunition under Spec. 31 - converting figures obtained under Spec. 31 to equivalents for AXS54

(c)with results of all firings as in (a) against flat plate of the same steel composition and heat treatment.

Comparison (a)

Results available under AXS54 and its revisions are strictly comparable with the results under consideration for grooved plates. They are summarized for all flat plates of the thicknesses involved in Table II.

TABLE II

Summary of Results of Tests Under AXS54*

Plate Thickness	Ballistic Limits - f.s.(a)	
	Mean of All Results	Mean of Highest 10% of All Results
5/16"	1830	2210
7/16"	2130	2460
1/2"	2290	2550
9/16"	insufficient data	

* - From Partial Reports of Test of Thin Armor Plate, A.P.G.

(a)- Tabulated and Interpolated from plot of about 100 results.

Plate	Equiv. Thickness	B.L.(f.s.)
G12(w/o cover plate)	5/16"	2440
G11(no cover plate)	7/16"	2478
G12(with cover plate)	7/16"	2590
G10(with cover plate	1/2"	more than2701
G11(with cover plate	9/16"	more than1769(cal.50)

Comparison (b)

The exact difference in foot-seconds in ballistic limit determination between the definition of Spec. 31 and AXS54 is very hard to ascertain. In some few cases no difference has been noted. In the great majority of cases, however, there is a difference of from 250 to 500 foot-seconds in the results obtained. Averages of the available results show a difference (in favor of Spec. 31) of 300 f.s. for 1/2" plate and of 400 f.s. for 1/4" plate. 750 f.s. will, therefore, be deducted arbitrarily from the averages obtained of tests made under Spec. 31. Since there were some 900 plates in this group, both face-hardened and homogeneous, the actual results and then the converted results will be shown in Table III.

TABLE III

Summary of Results of Tests Under Spec. 31.*

Plate Thickness	Ballistic Limits - f.s.(a)			
	Mean of All Results	Converted to AXS54 Equivalent.	Mean of Highest 10% of All Results	Converted to AXS54 Equivalent
5/16"	1980	(1630)	2430	(2080)
7/16"	2390	(2040)	2740	(2390)
1/2"	2600	(2250)	2900	(2550)
9/16" (cal. .50)	2000	(1650)	2500	(2150)

* - From Partial Reports of Test of Thin Armor Plate, A.P.G.

(a) Tabulated and Taken from Plot Involving about 900 results.

Plate	Equiv. Thickness	B.L.(f.s.)
G10 (w/o cover plate)	5/16"	2440
G11 (w/o cover plate)	7/16"	2478
G10 (with cover plate)	7/16"	2590
G10 (with cover plate)	1/2"	more than 2701
G11 (with cover plate)	9/16"	more than 1769 (cal. .50)

Comparison (c)

The plates used for grooving were homogeneous plates of the composition and heat treatment described at the beginning of this report. Plates submitted under AXS54 have practically all been face-hardened plates. However, twenty-nine homogeneous plates of this composition and heat treatment have been tested under Spec. AXS54. The results obtained were as follows:

1/4" Plates: - B.L.-1215, 1456, 1324, 1441, 1195, 1183, 1176, 1173, 1247, 1229.

Average 1264.: High 1456.

3/8" Plates: - B.L.-1738, 1811, 1762, 1844, 1755, 1877, 1854.

Average 1808: High 1877.

1/2" Plates: - B.L.-2242, 2675, 2518, 2431, 2296, 2304, 2370, 2326, 2451, 2445.

Average 2406 : High 2675.

3/4" Plate: - B.L.-1873

1" Plate: - B.L.-2445

The averages and highest values obtained were plotted in Figure 4. From this plot the relative limits of the grooved plates under consideration may be compared. The one value for the cal. .50 equivalent is very presumptive. The values for the other plates, however, form a very fair basis for the comparison shown in Table IV.

TABLE IV

Summary of Results of Ballistic Tests

Homogeneous .50C.-Cr-Mo-Va Armor Plates.-AXS54*

Plate Thickness	Ballistic Limit - f.s.[a]	
	Average Result	Highest Result
5/16"	1550	1630
7/16"	2120	2265
1/2"	2400	2675
9/16"	(1470)[b]	

* - From P.R. Tests of Thin Armor Plate, A.P.G.

(a)- Interpolation from Fig. 1

(b)- Extrapolation - (very questionable)

Plate	Equiv. Thickness	B.L.(f.s.)
G12(w/o cover plate)	5/16"	2440
G11(w/o cover plate)	7/16"	2478
G12(with cover plate)	7/16"	2590
G10(with cover plate)	1/2"	more than 2701
G11(with cover plate)	9/16"	more than 1769(cal..50)

The results shown in Table IV are strictly comparable. They were obtained upon plates of the same composition and heat treatment and under the same firing conditions. The increased ballistic limit for the same weight of material disposed as in these grooved plates was as follows:

Plate	Exceeded Best B.L. of same Wt of Identical Flat Plate by
G12(w/o cover plate)	50%
G11(w/o cover plate)	9 1/2%
G12(with cover plate)	14 1/2%
G10(with cover plate)	more than 1%
G11(with cover plate)	more than 20%*

*-Doubtful - data insufficient.

Discussion

1. These grooved plates developed ballistic limits from 18 to 36% above those required in present specifications (Table I and summary following).

2. They were from 9% to 50% more efficient than the best of all plates on record of the same composition and heat treatment. (Table IV)

3. They were from 1% to 12% better than the average of the best 10% of all plates of all types tested at the Proving Ground under the present specifications.(Table II)

4. Although there may be differences of opinion as to the exact difference between Spec. 31 and Spec. AXS54 insofar as their definitions of ballistic limit are concerned, it is evident that the grooved plates under consideration were somewhat better than the best 10% of all of the large number of plates tested under Spec. 31. (Table III)

5. A plate weighing that of 1/2" flat plate successfully withstood cal. .30 APTl High Vel. ammunition. This ammunition was developed under an objective set by the Chief of Staff to penetrate 1/2" armor at 200 yrd. The results set forth in M.O.C.M. May 10th, 1934 show how successfully that objective was met. It is, therefore, of importance from the opposite point of view to have obtained a test plate of 1/2" armor weight which successfully withstood this ammunition as did plate G10.

6. The value of the cover plate in this type of armor is not clear. The cover plates used were of the same material as the grooved plate. Report #710/32 shows that unless these cover plates were heat treated to great hardness they did more harm than good. The present results do not make clear the advantage of the cover plate. Two of the plates were equivalent to 7/16" armor in weight. The one with the cover plate (G12) was somewhat better than the one without a cover plate (G11). G10, which weighed the same as 1/2" armor and which stopped the T1 ammunition, had a cover plate. On the other hand, the greatest single increase in efficiency was shown by G12 without a cover plate. In practice these cover plates would be shot off the grooved plate after a number of rounds and would have to be replaced. Further investigation will be necessary before any definite decision can be made regarding the necessity of cover plates in construction of this type. It is felt that the only time the cover plate is of value is when the bullet would otherwise strike directly at the bottom of a groove. The area of groove bottoms (1/16" on either side of each groove) constitutes about 10% of the surface area of the plate. Therefore, the cover plate is useful to resist about 10% of the rounds fired at any plate and without it the plate should be just as effective against 90% of the rounds fired against it.

7. A grooved plate of the type shown presents no unusual difficulty in rolling. It would be rolled down to a flat slab of desired thickness and then passed between pairs of flat rolls and a grooved roll to the desired size. The cost of manufacture (except for the initial cost of the grooved rolls) should not be any greater than the cost for an equal tonnage of flat plates. No difficulties were experienced in heat treating these grooved plates.

Conclusions

It is concluded that the method described herein of disposing of a given weight of armor plate in a plate grooved on the front and flat on the back has resulted in a very definite increase in ballistic efficiency.

Recommendations

It is recommended that this type of armor plate be given further study in order that full advantage may be taken of mechanical means thus available for so disposing of a given weight of material to obtain its maximum usefulness.

Respectfully submitted,

D. J. Martin
1st Lt. Ord. Dept. U.S.Army

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GROOVED ARMOR PLATE

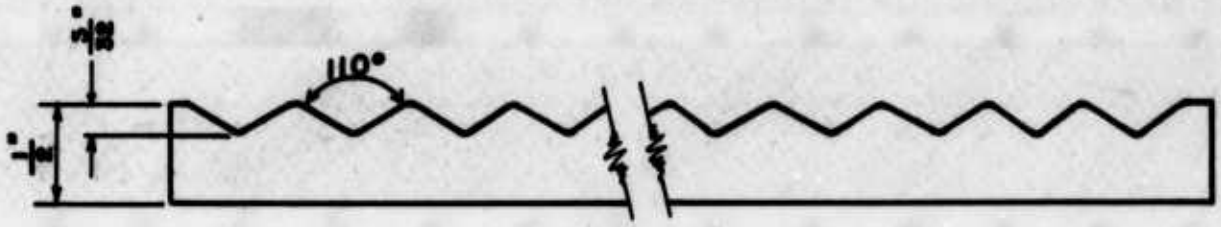

PLATE G10
FIG. 1

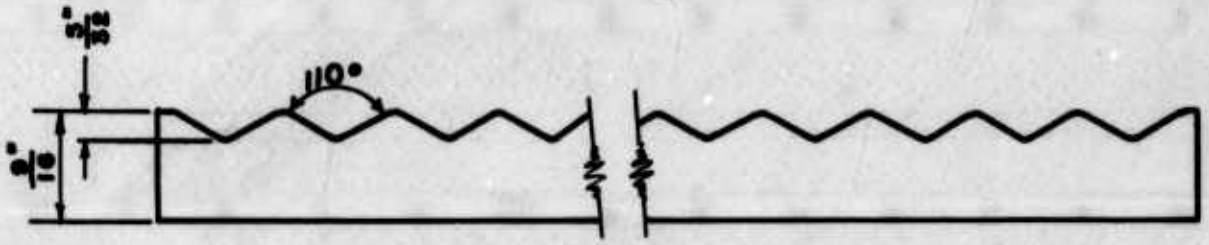

PLATE G 11
FIG. 2

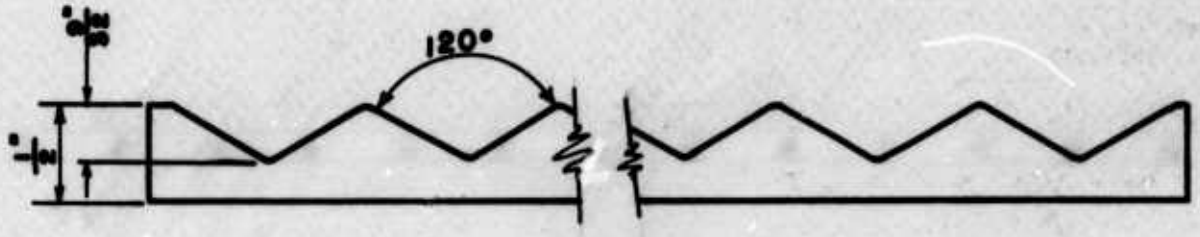

PLATE G12
FIG. 3

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PLATE G 10

FIG. 1.

PLATE G 11.

FIG. 2.

PLATE. G 12.

FIG. 3.

SK. 710/53.

FIGURE 4

BALLISTIC LIMIT VS. THICKNESS OF PLATE.

CR-MO-VA.-HOMOGENEOUS PLATES.

SPEC. AXS. 54